EEDP-01-4
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Environmental Effects of Dredging
Technical Notes

ENGINEERING CONSIDERATIONS FOR CAPPING SUBAQUEOUS DREDGED MATERIAL DEPOSITS -- DESIGN CONCEPTS AND PLACEMENT TECHNIQUES

PURPOSE: The following two technical notes present information applicable to planning and constructing dredged material capping projects:

EEDP-01-3 Background and Preliminary Planning

EEDP-01-4 Design Concepts and Placement Techniques

This second note discusses the selection of cap material and presents the results of recent equipment and technique demonstrations. Monitoring guidelines are also described.

BACKGROUND: In order to ensure the effectiveness of capping, such projects cannot be treated simply as a modification of conventional disposal practices. A capping project involves an engineered structure with design and construction requirements that must be met, verified, and maintained over the design life. This is not to say that traditional equipment and operational methods cannot be applied to capping contaminated materials. In fact, they have been used with good success.

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Considerations for Cap Materials and Cap Design

One of the principal design decisions in a capping project is the nature and thickness of the cover material to be placed over the contaminated dredged material. The cap provides the isolation necessary to control the movement of contaminants out of the dredged material into the overlying water column and to prevent direct contact between aquatic biota and the contaminants. The cap also performs the important physical function of stabilizing the dredged material and protecting it from transport and dispersion away from the site. The design of the cap, therefore, requires a two-fold approach. It must result in a capping layer with properties and thickness such that it functions as an adequate seal, yet the layer must remain unbroken and resist resuspension and transport by the bottom shear stresses at the site.

Shields and Montgomery (1984) suggested that potential capping materials can be classified as inert, chemically active, or sealing agents. They, as well as Johanson, Bowen, and Henry (1976), reviewed characteristics and applicability of several types of material. Although chemically active materials and sealing agents (e.g., grouts, polymer films) have some attractive capping properties, general experiences with them are limited and specific cases of use on subaqueous dredged material deposits are nonexistent. As shown in Table 2 of Technical Note EEDP-01-3, all projects to date have used inert materials (clean sand and silt) for capping, and it is unlikely that this trend will change in the immediate future. Sufficient volumes of clean sediment are usually available even in contaminated reaches, and techniques and equipment for placing such materials as capping are also readily available.

Contaminant isolation

The effectiveness of inert sediment as a contaminant-isolation technique has been evaluated by Brannon et al. (1985). Their experiments used modified flow-through reactor units containing contaminated sediment and capping material. To assess effectiveness, they performed chemical analyses on water samples from the reactor water columns and monitored contaminant uptake in indicator clams and polychaetes. In their testing matrix, samples of a sand, silt, and clay were evaluated at various thicknesses and both with and without the presence of bioturbation organisms. Results indicated that the cap materials with the higher percentages of clay and silt were generally more effective than sand in preventing the movement of contaminants into the water

column. The thickness of the cap, however, especially in the presence of bioturbation, is apparently as important as the type of material since thicker caps of each of the three materials were equally effective. Certainly additional work in the general area of contaminant isolation is suggested and testing of specific contaminated sediments is advisable for design.

The effective thickness necessary for isolation must be specified considering any incorporation into the underlying sediment and must be maintained over the life of the project. However, given the difficulty of constructing and maintaining a conformal cap within a tolerance of inches (e.g., conventional fathometer accuracy is on the order of 6 in.), practical cap thicknesses specified as an operational requirement are going to be on the order of 3 ft. It is likely that for all but the most unusual case, constructability and erosional considerations will control the minimum cap thickness.

Cap erodibility

Sediment behavior. The cap design must specify the necessary thickness and materials that will maintain that thickness under the effects of long-term erosion and transport. Sediment transport is a complex process made even more complicated by the mechanical effects of the dredging on the sediment and by the configuration of the disposal mound. Although sediment can be classified in a number of meaningful ways, the information most commonly available in dredging projects is particle size (percent sand, silt, and clay) and some indication of the plasticity (e.g., inferred from Atterberg limits, USCS class, or possibly shear strength data).

Noncohesive sediment (sand and some silt) transport as individual grains typically in a continuing series of discrete erosion and deposition events. The transport is primarily dependent on the size, shape, and weight of the sediment particles and on the magnitudes of the fluid forces exerted on them.

For sediment generally classified as cohesive (silt and clay), the potential erodibility is more dependent on the condition of the cohesive bonds between the particles than on the characteristics, especially size, of the individual particles. Since fine-grained sediment has such poor settling properties, the particles are not easily redeposited once suspended and tend to move in a suspended layer above the bottom or to remain stationary in such a layer (i.e., fluff). Their hydrodynamic behavior is complicated by the effects of flocculation. In addition, the initial bonding is influenced by the method of dredging and placement, and the longer-term surface cohesion is

related to the nonlinear, time-dependent consolidation process.

Subaqueous caps constructed predominantly of plastic clay-sized sediment are feasible and, in fact, have been used (i.e., Rotterdam Harbor project listed in Table 2 of Technical Note EEDP-01-3). Once placed, such material is more resistant to erosion than noncohesive sediment and can provide an effective seal. However, because of the difficulty in handling and uniformly placing such materials, this must be thought of as an exception to a typical project. It is more likely that a cap would be constructed of some combination of sand and silt with low to moderate plasticity. It must be noted that, for such deposited material, the apparent grain size presented to the fluid may be different than that observed in laboratory classification. It is common for mixtures to undergo initial sorting and winnowing that results in a surface layer having an average grain size much larger and less likely to transport than the remaining material. In addition, biological activity is known to aggregate grains of sediment providing a degree of self-armoring and apparent cohesion in relatively short periods of time.

Predictive methods. There are four principal approaches that can be applied to predicting the resuspension and transport of material from a capped mound (Dortch 1986): steady-state analytical methods; time- and rate-dependent analytical methods; physical and numerical modeling; and field and laboratory measurements. Randall (1986), summarizing the work of Dortch (1986), described the applications of each method as follows.

The first approach assumes steady or constant conditions and is representative of long-term average conditions. Such an analysis is the simplest to apply but fails to show results that can occur during episodic events such as storms. A steady-state analytical method developed for dredged material disposal mounds and applied to a site in San Francisco Bay was reported by Trawle and Johnson (1986).

The second approach is more difficult to apply, but it includes the effects of extreme events and variations in rate-dependent processes. Continuous physical processes are discretized into a series of distinct events for analysis. A time- and rate-dependent analysis of a dredged disposal site in Tampa Bay, Florida, was conducted by Williams (1983). Trawle and Johnson (1986) also extended their method to nonsteady conditions.

The application of numerical models to disposal mound transport can yield valuable information and detail, but also requires significant effort

and potentially high cost for the more sophisticated multi-dimensional versions. Such methods generally require the use of both a hydrodynamic model and a sediment transport model either in coupled or uncoupled form.

Little information is available on the application of field or laboratory measurements to the study of the long-term fate of dredged material placed in subaqueous disposal sites. (For a summary of investigations of short-term fate, see Technical Note EEDP-01-2.)

In all these predictive methods, the focus is on resuspension and transport (typically based on incipient motion of individual grains) of mound or cap material. However, the net effect on cap stability must consider the eventual fate of resuspended cap (and adjacent bottom) material. It would be a rare site that experienced net transport in all directions away from the mound. Certainly some sites may experience gradual losses in volume over time and storm events can result in significant, temporary profile lowering at a mound; but verified general models for predicting the net effects of resuspension, transport, and redeposition are not yet available. The provision of an increased thickness of cap material at initial construction (advance nourishment) together with monitoring and maintenance are recommended as interim measures to ensure that the effective cap thickness is provided for the design life of the disposal area.

Placement Equipment and Techniques

This discussion of placement techniques applies equally to the contaminated dredged material to be capped as well as to the capping material itself. However, the intent of various techniques may differ between the two. Previous investigations (see Technical Note EEDP-01-2) have demonstrated that dredged material released at the water's surface, both by instantaneous discharge from barges or hopper dredges and by continuous hydraulic pipeline discharge, tends to descend rapidly to the bottom as a dense jet with minimal short-term losses to the overlying water column. Potentially undesirable effects can still result from impact, scour, and spread of the material over the bottom. Two objectives for the placement of both cap and underlying dredged material are control and accuracy. In all cases, accurately controlled placement reduces required areas, confines benthic impacts, results in economy of materials, and can reduce monitoring effort.

In the case of some contaminated dredged material, an additional objective necessary may be to isolate the material from the water column during at least part of its descent. This isolation can minimize mixing and potential chemical releases; significantly reduce entrainment of site water, thereby reducing disposal volumes; and negate any possible effects of currents during disposal. Technologies to accomplish these objectives are described in the following paragraphs, but they should be viewed as conservative measures and their need on a specific project should be clearly established. Experience has shown, for example, that contaminated silt and clay that have been dredged by clamshell will tend to remain in clumps during descent, offer little time or surface area for chemical release (certainly at an interstitial level), and form nonflowing discrete mounds on the bottom.

Specific additional considerations for placement of clean inert capping material focus more on controlling the rate of its application to the contaminated material. Conventional point dumping of moderately cohesive capping material may produce sufficient impact energy to displace soft deposits of underlying contaminated dredged material. Variables include the depth of water, rate of release, likelihood of clod formation versus transition to discrete particle sedimentation, and the strength of underlying material.

Modified surface release

Conventional equipment can be used to place cap material in many cases with only minor modifications. In the Duwamish contained aquatic disposal (CAD) demonstration (see Technical Note EEDP-01-03, Table 2), clean sand was successfully sprinkled over the contaminated dredged material by slowly opening a conventional split-hull barge over a time frame of just under one hour. The sand descended in a generally continuous manner with no displacement of the dredged material. Three barge loads were applied in an overlapping pattern to produce the necessary coverage. Clean coarse capping material could also be applied by surface discharge of a conventional hydraulic pipeline or by spray-booms analogous to side casting.

Submerged discharge

The use of a submerged discharge or closed conduit of some type to place the dredged material and/or the cap is a further level of control that is available. To the extent that the conduit extends through the water column and physically isolates the discharge, it can meet the objectives described

head to reduce velocities and place material near the bottom, it can meet the objective for capping. A number of conduit technologies are available or have been suggested to place dredged material and/or capping material through the water column.

Submerged diffuser.

A submerged diffuser (Figure 1), originally designed as part of the Corps' Dredged Material Research Program, has been successfully field tested in the Netherlands at Rotterdam Harbor and as part of an equipment demonstration project at Calumet Harbor, Ill. (McLellan and Truitt 1986). The diffuser

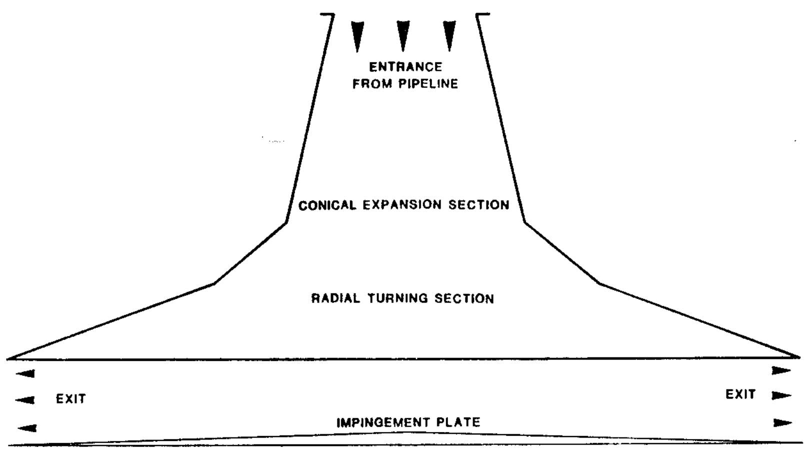

Figure 1. Schematic of submerged diffuser

minimizes upper water column impacts and especially improves placement accuracy and controls sediment spreading, which in turn reduces benthic impacts. By routing the slurry first through a conical expansion and then a combined turning and radially divergent diffuser section, the discharge is released parallel to the bottom and at a lowered velocity. The design of the diffuser section can be modified to suit project needs.

Results of the Calumet diffuser demonstration showed that the discharge velocity was reduced to 25 percent of the measured pipeline velocities. At a distance of 15 ft from the diffuser, the velocity was 5 percent of the average pipeline value (Figure 2). The discharged material was confined to the lower 20 percent of the water column with no increase in suspended solids above that point.

The diffuser could be employed as a direct connection to a pipeline dredge or as a modification to hopper dredged or mechanically dredged material

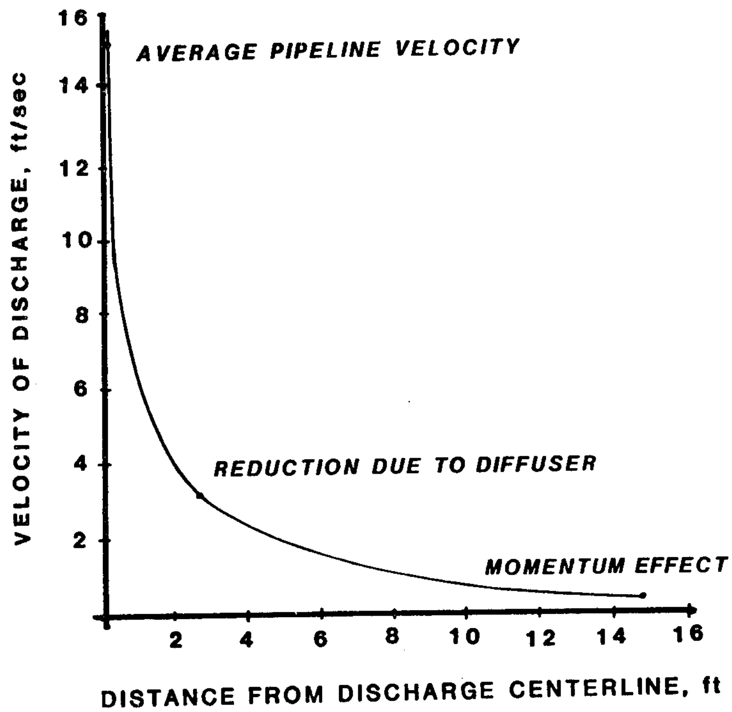

Figure 2. Changes in velocity of dredged slurry through diffuser and adjacent water column

disposal techniques (Figures 3 and 4). For the latter cases, a reslurring pump-out capability would be required. The pipe connecting the surface/ support barge to the submerged diffuser head can be of relatively small diameter (conventional pipeline sizes) and can be semirigid or flexible if the head is controlled independently by cable or other moorings.

Gravity-fed downpipe (tremie). This technology consists of a large-diameter conduit extending from the surface through the water column to some point near or above the bottom. Dredged material would be placed into it either as a slurry or by being mechanically removed from a scow. Isolation from the water column is achieved, and placement accuracy is improved. However, little reduction in momentum or impact energy takes place over conventional bottom dumping. Because the conduit has a large cross-sectional area and is a rigid structure, site conditions (e.g., currents, water depth, sea state) would exert considerable influence on its use and cost.

Hopper dredge pumpdown. Some hopper dredges have pump-out capability by which material from the hoppers can be discharged like a conventional hydraulic pipeline dredge. In addition, some have further modifications that allow pumps to be reversed so that material can be pumped down through the dredge's

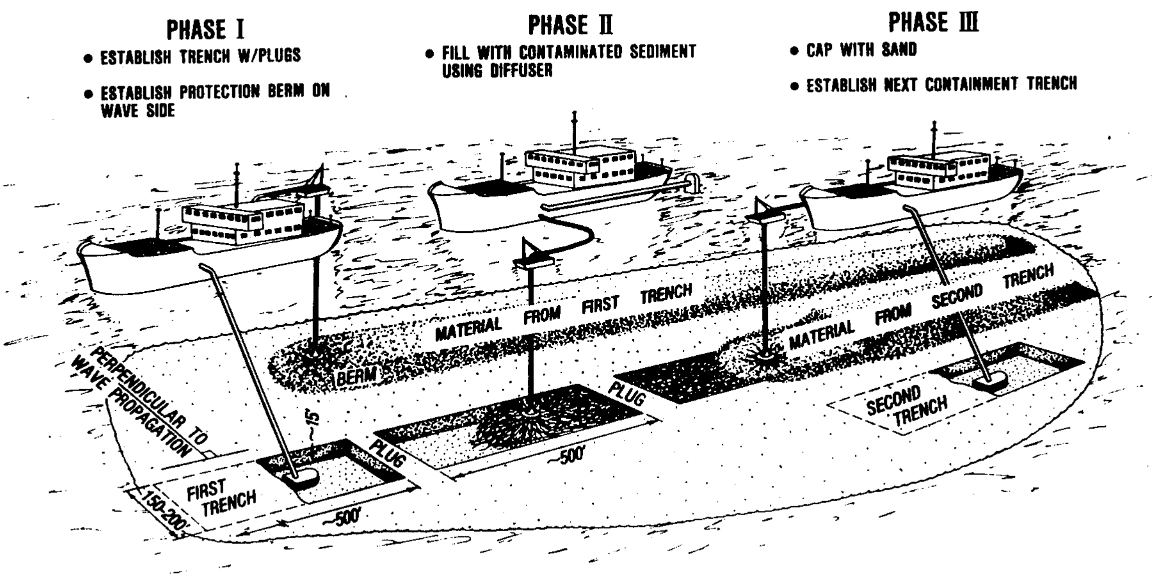

Figure 3. Conceptual design of CAD site using hopper dredge and submerged diffuser

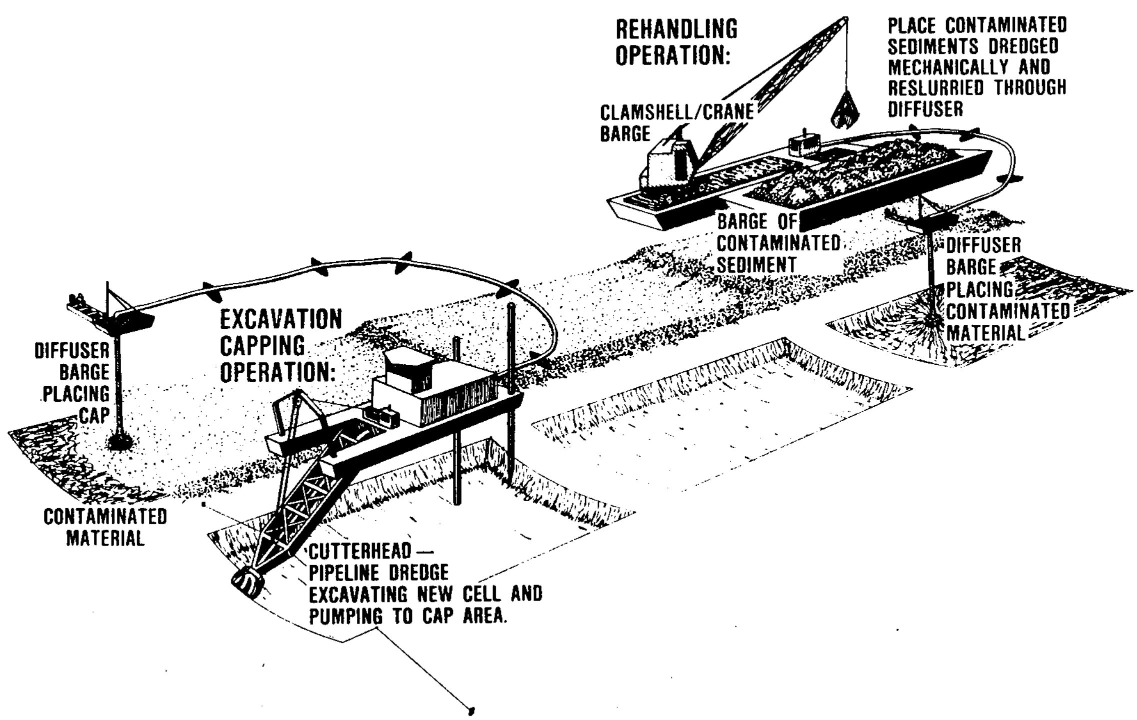

Figure 4. Conceptual design of CAD site using barge pumpout and submerged diffuser

extended dragarms. Because of the expansion at the draghead, the result is similar to use of a diffuser section. Pumpout depth is limited, however, to the maximum dredging depth of the hopper.

Monitoring

Monitoring at the disposal site must address both contaminant migration and physical condition of the site and must do so over time. Three basic categories of monitoring are suggested based on their time frames and intent.

1. Construction monitoring. Monitoring should take place before, during, and immediately following the construction operation. Background chemical characterization of the site will be necessary to serve as a baseline for comparisons. Water samples should be take during the placement of the contaminated dredged material and during capping primarily for monitoring resuspension in the area. However, the focus of the construction monitoring should be on bathymetry, accurate positioning during discharge, and accounting for the volume/mass of sediment handled. Moored buoys will be required at the site together with a real-time and recording positioning system. Replicate soundings must be taken frequently during placement of the dredged material and the capping material. Side-scan sonar and video equipment could also be used to verify conditions. Cores should be taken through the completed cap to verify its thickness and for sediment chemistry characterization.

2. Long-term monitoring. Similar water column sampling and sediment core series should be completed periodically after construction. Bathymetry and consolidation should also be measured at these intervals.

3. Contingency plans. In addition to the above regular monitoring, specific contingency plans should be developed to complete a similar monitoring series after a prespecified threshold storm event or ship incident.

Summary

A properly designed and placed cap provides the isolation necessary to control the movement of contaminants out of deposited dredged material into the overlying water column, and to prevent direct contact between aquatic biota and contaminants. It also performs the physical function of stabilizing the dredged material mound and protecting it from transport. Laboratory test

methods are available to estimate the cap thickness required for isolation. However, this thickness is considered a minimum requirement and must be maintained in spite of erosion at the site.

Equipment and techniques for placing both dredged material and cap should consider the objectives of control and accuracy. Technologies such as the submerged diffuser are available to provide controlled accurate placement and to accomplish the additional benefit of isolating the material from the water column during descent.

Monitoring is an important aspect of construction verification and site management. Typical monitoring includes chemical characterization of site and deposited materials, bathymetry, mound consolidation, and cap thickness.

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